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# THE PRESSURE PROFILE OF A ROCKET PAYLOAD AFTER NOSE-CONE EJECTION

*by N. McIlwraith and D. L. Lind*

*Goddard Space Flight Center  
Greenbelt, Md.*



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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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## SUMMARY

A measurement was made of the pressure at the instrument rack of a typical sounding rocket. It was found to be more than four orders of magnitude higher than the standard ambient pressure at nose-cone ejection at 687,000 feet. This difference decreased to about 3 orders of magnitude after a few seconds. Ram pressure contributed about one order of magnitude, but the major pressure differential was due to the outgassing of the payload.

Ground-based pressure simulation experiments were conducted to determine if an experiment which is susceptible to corona breakdown could be operated without a vacuum pump. It was shown that pressure conditions close to the payload do provide a sufficient differential to evacuate an experimental package if large pump-out ports are provided. Analysis showed that the major portion of the gas load was water vapor associated with a Room Temperature Vulcanizing (RTV) silastic potting compound used in the experiment.



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# THE PRESSURE PROFILE OF A ROCKET PAYLOAD AFTER NOSE-CONE EJECTION

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## INTRODUCTION

This report describes experiments conducted to determine the pressure conditions close to the instrument rack of a rocket such as an ARGO D4 immediately after nose-cone ejection, and to discover whether these conditions allow the use of the secondary emission plasma detector without a sealed continuously pumped system with its weight and size penalty.

It has been shown that the pressure conditions close to the payload do provide sufficient differential to evacuate the plasma experiment if large pump-out ports are provided. The major portion of the gas load from the plasma experiment was found to be water vapor, particularly that associated with the Room Temperature Vulcanizing (RTV) silastic potting compound. It is presumed to be both absorbed and adsorbed.

## DESCRIPTION OF SECONDARY EMISSION PLASMA DETECTOR

The essential part of this instrument\* consists of an aluminum electrode maintained at a potential of  $-15$  kv with respect to the rest of the structure. Positive particles from the ambient plasma are attracted to it, and the secondary electrons emitted are accelerated away from it and counted by a scintillation counter. This electrode is mounted inside a grounded aluminum can approximately 4 inches in diameter, and any corona discharge between this can and the electrode temporarily prevents proper operation of the device. A diagram is shown in Figure 1.

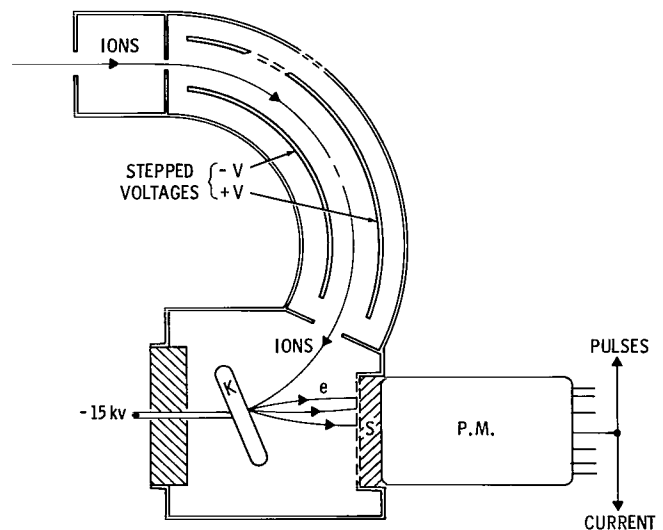


Figure 1—Plasma experiment detector.

\*Ogilvie, K. W., McIlwraith, N., Zwally, H. J., and Wilkerson, T. D., "A Detector-Analyzer for Studying the Interplanetary Plasma," NASA Technical Note D-2111, February 1964.

## DESCRIPTION OF ROCKET-FLIGHT 8.18 EXPERIMENT

On September 29, 1963, the secondary emission plasma detector was launched from Wallops Island, Virginia as part of the payload of an ARGO D4 rocket designated as flight 8.18. Power was applied to the 15-kilovolt supply at an altitude of 825,000 ft 10 seconds after nose-cone ejection. At this time the telemetry showed spurious counts indicating a corona discharge. This data was later simulated in the laboratory using the back-up plasma detector and a bell jar pressure on the order of 100 microns of Hg. This corona continued past apogee where the telemetry failed. There was, however, a decrease in the discharge just prior to telemetry failure suggesting a lowering of pressure inside the detector toward an acceptable level.

During development of this rocket experiment the pump-out problem was considered and small pump out holes were provided on each of the electronic packages and on the detector chamber in which the high voltage electrode is located. These holes were on the order of 0.125-inch in diameter.

Calculations using the area of the slit and the holes indicated a pump-down time of the order of 1 second, and the pressure under the nose cone was estimated to be 10 microns of Hg\* at 708 K ft. There was a delay of 10 seconds before power was applied to the 15-kilovolt supply after nose-cone ejection, and 2 seconds were required for the high voltage to rise. It was considered that this time delay was sufficiently long.

## ANALYSIS OF FLIGHT 8.18

Post flight analysis and laboratory simulation showed that the pressure inside the detector chamber must have remained well above  $10^{-4}$  mm of Hg, in fact, on the order of 30 microns of Hg for several hundred seconds after nose-cone ejection. In the laboratory, discharges were shown to occur if the pressure in the detection chamber of the apparatus was above about 10 microns of Hg when the high voltage was applied. Factors that were considered to contribute to the high pressure which must have occurred, include (1) outgassing of the payload, leading to higher than ambient pressure at the exit of the pumpout holes, and (2) heavy outgassing by the inside of the detector.

Ram pressure calculations for 708,000 ft (nose-cone ejection altitude) indicate a value of  $10^{-5}$  mm of Hg, one order of magnitude above the ambient pressure. This is one order of magnitude below the pressure that can sustain any kind of corona discharge in the detector box (i. e.,  $10^{-4}$  mm of Hg). If the discrepancy were due to large-scale outgassing of the whole payload, it is possible that no increase in the size of pump-out apertures would allow operation of the detector in a reasonable time. If this were the case, then, an active pumped system with a break-off mechanism would be required.

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\*This subsequently proved to be a low estimate. The pressure under the nose cone is  $\approx$  100 microns of Hg.



Pressure close to the payload could conceivably be several orders of magnitude greater than the ambient pressure tables predict. Since the hot case of the X-248 rocket motor remains with the payload after it has burned out, it was considered a possible source of gas.

A literature search showed that no conclusive evidence was available on the problem, therefore it was decided to mount a pressure gauge on a similar payload and so establish this parameter.

## DESCRIPTION OF FIRST VACUUM TEST

To test the effect of pump-out ports the plasma detector was re-designed with the two ports of high conductivity shown in Figure 2. These ports gave the complete structure a calculated pump-down time of a few milliseconds. A Philips ion gauge supply replaced the 15-kilovolt power supply and the photomultiplier was replaced by the Philips ion gauge which was thus able to measure pressure inside the detection chamber. A photograph of this modified system is shown in Figure 2.

On May 13, 1964, this version of the plasma detector was placed in a small vacuum chamber at Goddard Space Flight Center. To simulate the decreasing pressure environment of a rocket payload after nose-cone separation, the small chamber was connected through a quick-acting valve to a very large vacuum chamber. When the valve was opened, the pressure in the small test chamber fell rapidly to the pressure of the large chamber. The conductance between chambers was made as large as practical and is considered large compared to the conductance of the pumpout ports. The small chamber was pumped down mechanically to  $60 \pm 20$  microns of Hg. The large chamber at the beginning of the test was at  $1.3 \times 10^{-6}$  mm of Hg. After opening the valve, pressure in the small chamber was monitored and recorded on a chart recorder. The pressure in the small chamber at the end of 300 seconds was on the order of  $7 \times 10^{-4}$  mm of Hg, while that in the large chamber showed no change. Figure 3 shows the results of three consecutive operations. The most interesting features of these graphs are:

1. The very rapid fall to about 2 microns of Hg
2. The very long time to reach pressures below 1 micron of Hg
3. The progressive decrease in pressure for a given time as a function of number of cycles.

The first effect is due to the changeover from viscous to molecular flow which occurs for pressures of the order of a few microns. The second and third show the large effect of outgassing

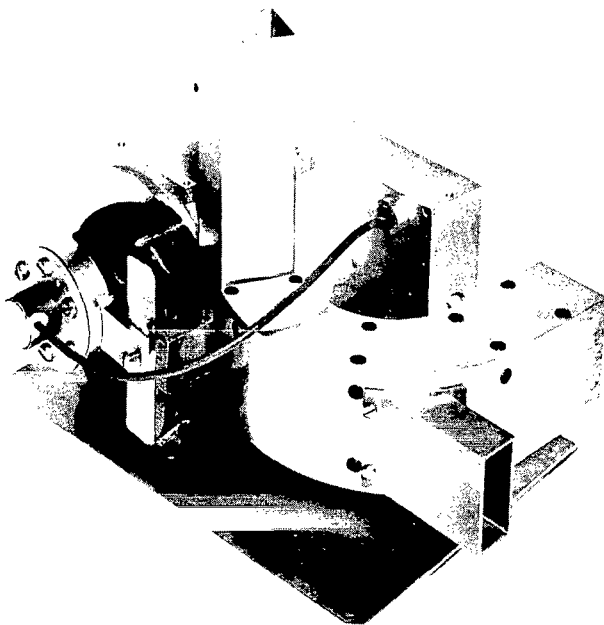


Figure 2—Pressure experiment showing pump-out ports.

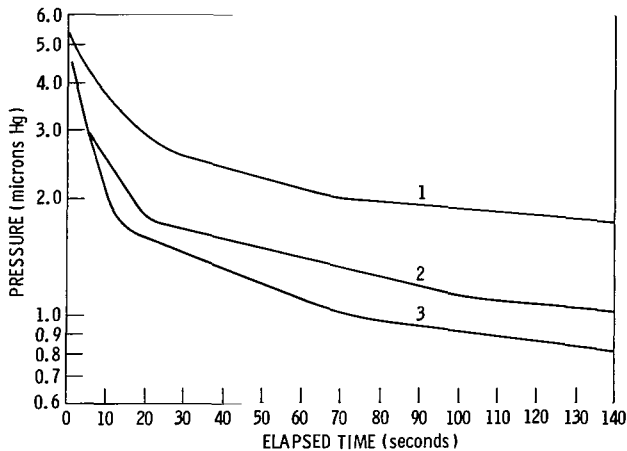


Figure 3—Pressure inside plasma detector (initially at 60 microns) versus time of exposure to large chamber at  $1.3 \times 10^{-6}$  mm Hg for three consecutive runs.

from the experiment. This will be discussed below, where it will be shown that at least 90% of this gas is water vapor.

## DESCRIPTION OF ROCKET PRESSURE EXPERIMENT

On October 19, 1964, a Philips ion gauge was launched from Wallops Island on a payload similar to Flight 8.18. The gauge was energized during the last few minutes of count down, and continuously through launch, ballistic flight and to impact. Although weak telemetry resulted in some blank spots in the data, the slowly varying nature of the pressure experiment allowed an easy interpolation. The pressure throughout the flight until the gauge was off scale is provided to at least within a factor of 2.

Figure 4 shows the rocket payload containing the Philips ion gauge pressure experiment. The sensing element is inside a cylinder  $5/8$  inch in diameter and  $1-1/2$  inch in depth. It is approximately 4 feet forward from the nozzle of the fourth stage which remains with the payload throughout the flight. It is only 2 feet from the front of the fourth stage case. Hot vapors could be evolved from any part of the case but most likely from the nozzle. This stage is the same X-248 motor which was used with the flight 8.18 rocket.

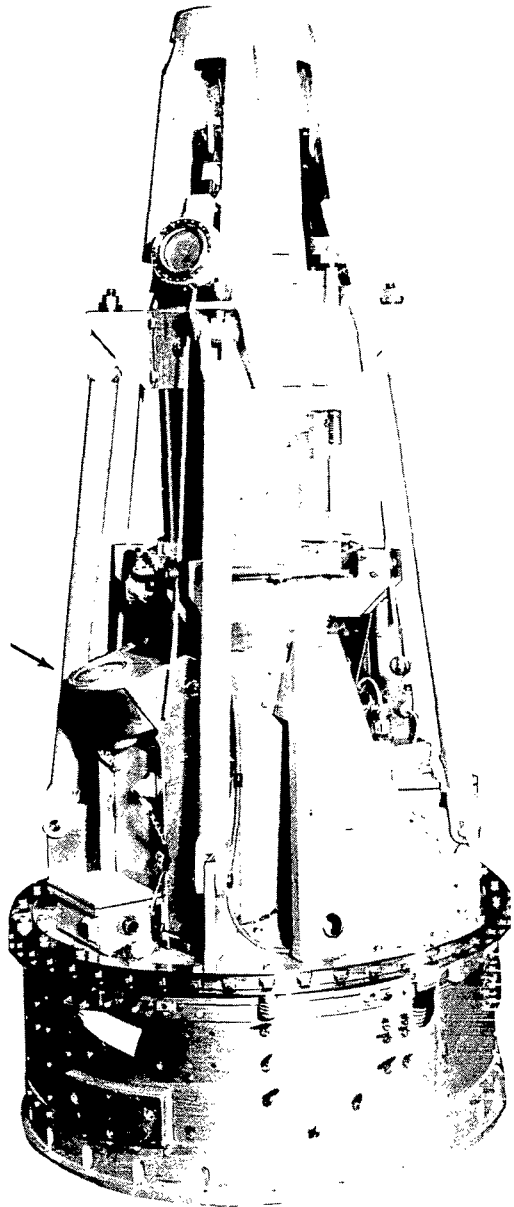


Figure 4—Argo D4 payload showing pressure experiment (arrow).

From the curve of Figure 5, it can be seen that the pressure drops to  $10^{-4}$  mm of Hg within 3 seconds of nose-cone ejection and to  $3 \times 10^{-5}$  mm of Hg in about 10 seconds. This is considered to prove conclusively that adequate pressure difference exists between the inside and outside of the payload to pump the experiment down quickly if sufficient conductivity can be provided. Outgassing of the rest of the payload is evidently not a problem.

## FURTHER PRESSURE TESTS

On November 19, 1964, a modified configuration of the plasma experiment was tested in the same pair of connected vacuum chambers which were used previously. The modified configuration of the experiment with the two pump-out ports was similar to that used in the first vacuum test, but with the 15-kv power supply of the plasma detector in place of the Philips ion gauge and with a photomultiplier to detect any corona in the chamber. One of the pumping ports was a 6-inch long  $1'' \times 1''$  square tube, attached to the junction between the box and the electrostatic analyzer, the other was a  $1\frac{1}{2}$ -inch long rectangular tube  $\frac{1}{2}'' \times 1\frac{1}{2}''$  in cross section and attached to the electrostatic analyzer. The disposition of these tubes is the same as in Figure 2.

These were considered to be the largest ports which could be attached to the detector and still have it function correctly. The pump down time was calculated to be a few milliseconds.

To simulate conditions of nose-cone ejection in rocket flight, the small vacuum chamber was evacuated to 50 microns of Hg by use of a mechanical pump; the pumping line closed; and the valve operated. After a number of seconds, the high voltage ( $-15$  kv) was applied and the photomultiplier output monitored to detect evidence of corona. This experiment will not give conclusive results if the initial conditions at the time of opening the valve to the high vacuum are not always the same. This presents some difficulty since one of the factors of the initial conditions (outgassing) is dependent upon the past history of the apparatus and cannot be controlled precisely.

That outgassing is the controlling phenomenon is shown by a series of experiments summarized in Table 1.

The entries in this table are in the order in which the readings were taken. The discharge in the first trial was the only one observed even though the delay time was subsequently reduced and the pumping ports were partially closed. Between each trial the chamber was vented to atmosphere,

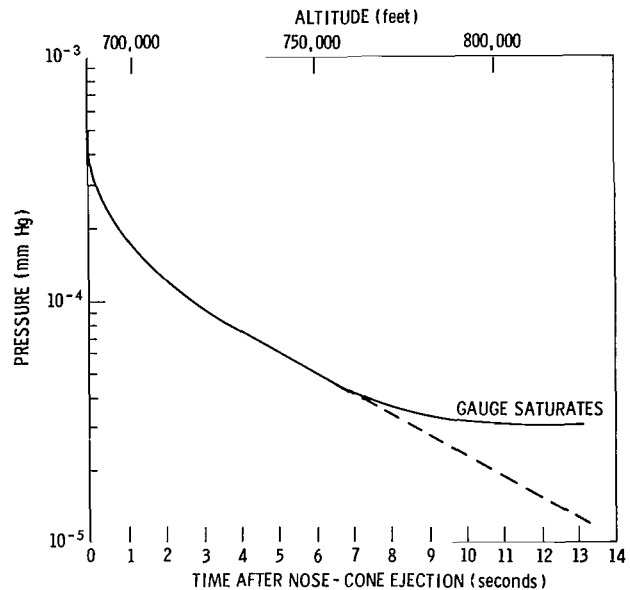


Figure 5—Results of the rocket pressure experiment.

Table 1  
Effect of Outgassing  
on Corona Discharge

Time between opening valve and switching on high voltage (seconds)	Both ports open	1 port closed
5	Discharge	—
10	No discharge	—
5	No discharge	No discharge
0	No discharge	No discharge

but pumped down again after a few minutes. It is believed that time on the order of 10 hours is required for appreciable adsorption of moisture and that history is the dominant factor, therefore a testing program sufficient to establish optimum parameters of pump-out ports would require several weeks and is beyond the scope of this study. Concern is limited to providing sufficient pump-out capability to allow application of high voltage to the plasma experiment within a short time after nose-cone ejection and with a fair confidence that corona will not occur.\*

## GAS ANALYSIS

On November 10, 1964 a complete set of components for the plasma detector in its rocket configuration was placed within a vacuum system. The gas analyzer was turned on at the earliest safe opportunity, which was at a pressure of about  $10^{-5}$  mm of Hg. A second analysis was made about one hour later when the instrument had fully stabilized and a third three hours after that. Between 90% and 95% water vapor was found along with quantities of hydrocarbons, nitrogen and oxygen. Many other constituents were present in appreciable amounts. These results are shown as Specimen 1 in Table 2.

Next the experiment was removed from the vacuum chamber, disassembled and the photomultiplier assembly alone was submitted for analysis. The results shown as Specimen 2 indicate that after considerable pumping the majority of vapors emanate from this component and lead to a suspicion of the silastic potting compound RTV-11 which is used to insulate the photomultiplier and which is present in large quantity. Therefore a third analysis was made on a piece of RTV-11 alone, a cylindrical sample of 1-1/2 inch diameter and 1/2 inch length which was poured about 1 year previously. The results are shown as Specimen 3.

It is important to note that no attempt was made in these analyses to maintain any quantitative relationship between material in the experiment photomultiplier assembly and RTV sample, so that no conclusive evidence exists as to the relative contributions of each component to the total gas load, however there are strong indications that RTV is responsible for a large part of this load.

\*If corona should occur, the pressure would drop fast enough to extinguish it in a few seconds. Such a discharge would not damage the plasma experiment.

Table 2  
Residual Gas Analysis\*

Date: 1964 Nov.	5	10	10	11	12	13	13	13	
Hour of day	1500	1110	1400	1000	1345	0020	0400	0800	
Pressure (10 <sup>-6</sup> mm of Hg)	Start	.39	8.0	2.3	.40	2.5	1.8	1.0	2.6
	Stop	.37	5.6	2.1	.38	2.4	1.6	1.0	.74
	Background (relative units)	Specimen 1 (relative units)			Specimen 2 (relative units)	Specimen 3 (relative units)			
Mass Number: 16	123	4,900	1,260	129	810	630	340	216	
17	990	47,000	12,000	1,000	810	6,300	3,300	2,100	
18	3,750	100,000	45,000	3,800	30,000	22,000	12,000	7,700	
27	49	570	180	39	120	56	41	32	
28	650	4,900	2,310	540	990	690	460	330	
29	68	660	225	48	153	70	51	39	
32	32	1,080	450	120	47	67	32	23	
41	74	900	300	65	213	84	68	55	
43	79	750	250	57	123	63	51	42	
55	48	630	216	45	120	53	41	34	
57	55	680	249	51	168	63	48	39	

\*Temperature 25°C; Ion current = 50  $\mu$ A

## CONCLUSION

It appears from the above results that it is indeed possible to use the plasma experiment on a rocket and to energize it a few seconds after nose cone ejection, provided that large pump-out ports are employed.

Since practical restraints limit the size of these ports, attention should be paid to the development of materials and techniques to secure components with minimum contribution to the gas load. Since the largest contribution is due to water vapor and this is undoubtedly due to adsorptive and absorptive properties of RTV, effort should be made to find a replacement for it.

Provision of large pump-out ports, attention to replacement of RTV wherever possible, coupled with a 10 second delay between nose-cone ejection and high voltage application, should ensure against discharge.

## ACKNOWLEDGMENT

The authors wish to thank Mr. George Goldenbaum of the University of Maryland for use of his equipment and laboratory in the calibration of the Philips gauge, Mr. J. E. Ainsworth for his valuable contributions in the conception of this experiment, and Mr. J. A. Glaab for his capable technical assistance.



## Appendix A

### Spacecraft Outgassing Under Vacuum\*

#### Introduction

The outgassing characteristics of spacecraft in a vacuum environment has received increased attention over the past few months due to the emphasis placed on maintaining sensor surfaces, such as optics, free of contamination. The possibility of the sensor becoming contaminated from outgassed constituents within and external to the experiment is real and will have to be dealt with. Absolute data on the quantity and type of constituents effluxed from a spacecraft under vacuum are not available; however, review of secondary data from thermal vacuum tests of Delta class spacecraft does permit a first approximation of the magnitude of the gas load contributed by these spacecraft.

#### Test Method

For the purpose of this study, the gas load is defined as the product of the volumetric flow rate across a plane (liters per second) and the pressure (microns of Hg) at which it is measured. The total gas load results from gas desorption from the chamber walls, spacecraft outgassing and in-leakage through pumps and seals. In order to determine the total gas load at a given vacuum condition, a balance between the chamber pumping capacity and the total gas load is utilized. The pumping capacity is calculated from the following expression:

$$Q = pS$$

where

$Q$  = pumping capacity (micron liters per second)

$p$  = pressure (microns of Hg)

$S$  = speed of the diffusion pump in liters per second at indicated pressure.

\*This paper by F. Brown of the GSFC Test and Evaluation Division is reproduced from the November 1963 monthly progress report for the Advanced Research Technology (ART) program and emanates from ART task 09 04 02 "Techniques for Simulating the Space Vacuum Environment."

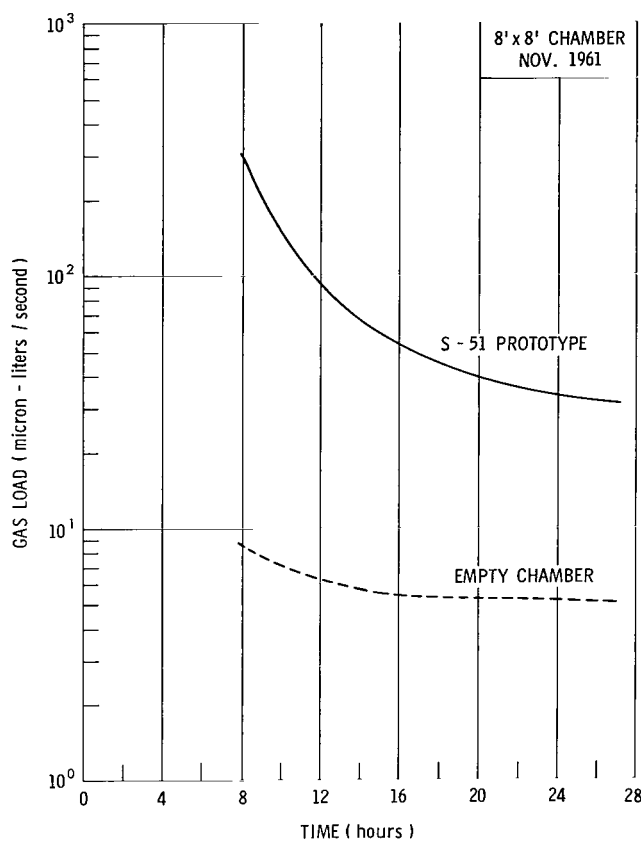


Figure 1—Gas-load vs time curves for S-51 cold test at  $-10^{\circ}\text{C}$ .

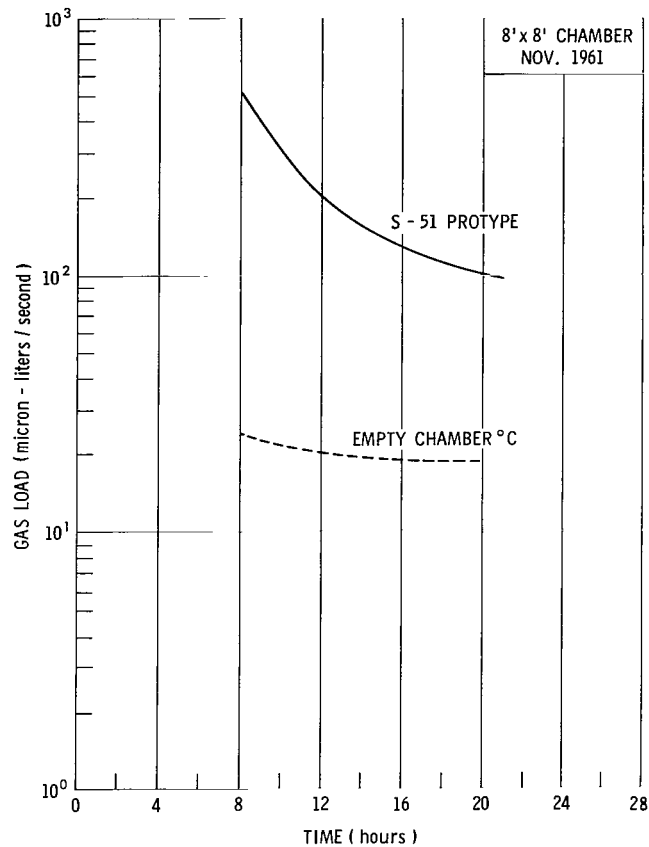


Figure 2—Gas-load vs time curves for S-51 hot test at  $+55^{\circ}\text{C}$ .

Table 1

Hot Test Spacecraft Gas Load Comparison

Time	Times Greater Than Empty Chamber				
	S-51 (1) Proto- type	S-52 (2) Proto- type	S-52 (3) Flight Unit	IMP (4) Proto- type	IMP (5) Flight Unit
10 Hrs.	12.6	—	—	3.8	1.7
15 Hrs.	6.9	—	—	3.1	1.5
20 Hrs.	4.3	1.0*	6.9 <sup>†</sup>	2.6	1.7
30 Hrs.	—	—	—	2.3	1.5
40 Hrs.	—	—	—	2.0	0.9
50 Hrs.	—	—	—	1.0	0.5

\*Preceded by 60 hours cold and transition to high temperature.

<sup>†</sup>Preceded by 156 hours cold and transition to high temperature.

Table 2

Cold Test Spacecraft Gas Load Comparison

Time	Times Greater Than Empty Chamber				
	S-51 (6) Proto- type	S-52 (7) Proto- type	S-52 (8) Flight Unit	IMP (9) Proto- type	IMP (10) Flight Unit
10 Hrs.	20.0	1.1	9.0	—	6.1
15 Hrs.	10.0	0.5	9.3	—	3.3
20 Hrs.	7.0	0.2	9.8	0.4*	3.0
30 Hrs.	—	—	7.6	—	2.4
40 Hrs.	—	—	6.6	—	1.8
50 Hrs.	—	—	6.0	—	1.4

\*Preceded by 52 hours hot and transition to cold temperature.



A curve of pumping capacity versus pressure is thus obtained for the system. The chamber background gas load is determined by operating the system and plotting the variation of  $Q$  versus time. By comparison of this profile with the  $Q$  versus time plot of the chamber with the spacecraft installed, the spacecraft gas load is determined.

A calibration test was performed by pumping down the empty 8'  $\times$  8' chamber at hot (+55°C), ambient (+25°C) and cold (-10°C) case temperatures, recording pressure and determining the background chamber gas load versus time profile. Similar data were recorded during the spacecraft hot and cold case thermal vacuum tests. The numeric difference in  $Q$  at times  $T_o$  to  $T_n$  describes the spacecraft.

## Results

Data are presented from thermal vacuum tests conducted on five Delta spacecraft from the S-51, S-52 and IMP programs. These data are to determine gas load trends only. Additional chamber instrumentation and rigorous experiment controls are required for absolute determination of the quantity and composition of the spacecraft gas load.

Figures 1, 2, 3, 4 and 5 review plots of gas load versus time from data acquired during the S-51, S-52 and IMP hot and cold thermal vacuum tests. Tables 1 and 2 group these data and express the spacecraft gas load as a factor of the chamber.

## Conclusions

The spacecraft tested at elevated temperatures contributed gas loads in the range of from approximately two to thirteen and one to seven times the background gas load of the chamber

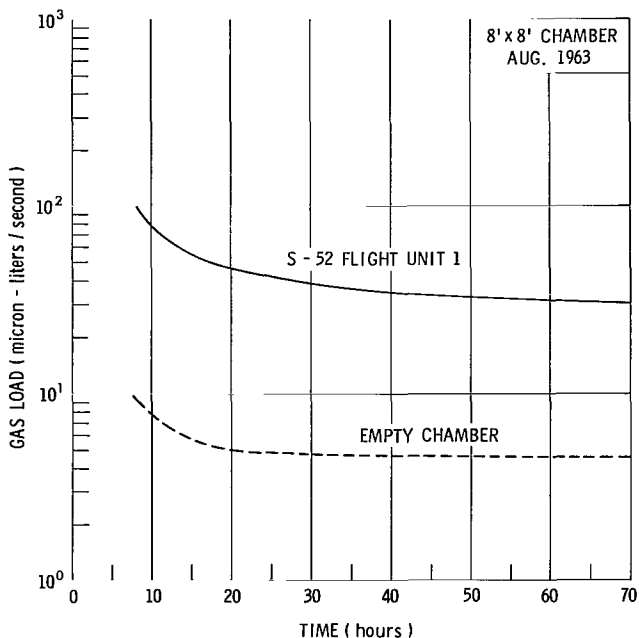


Figure 3—Gas-load vs time curves for S-52 cold test at -10°C.

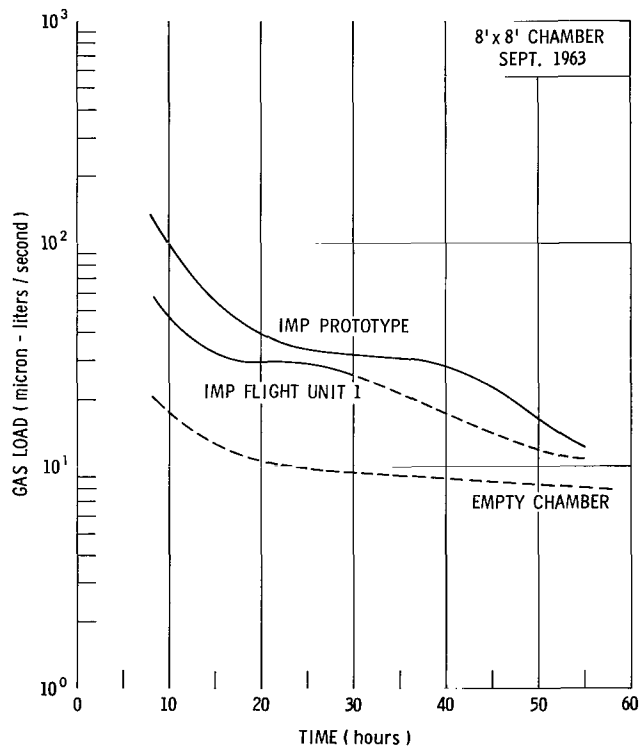


Figure 4—Gas-load vs time curves for IMP hot test at +35°C.

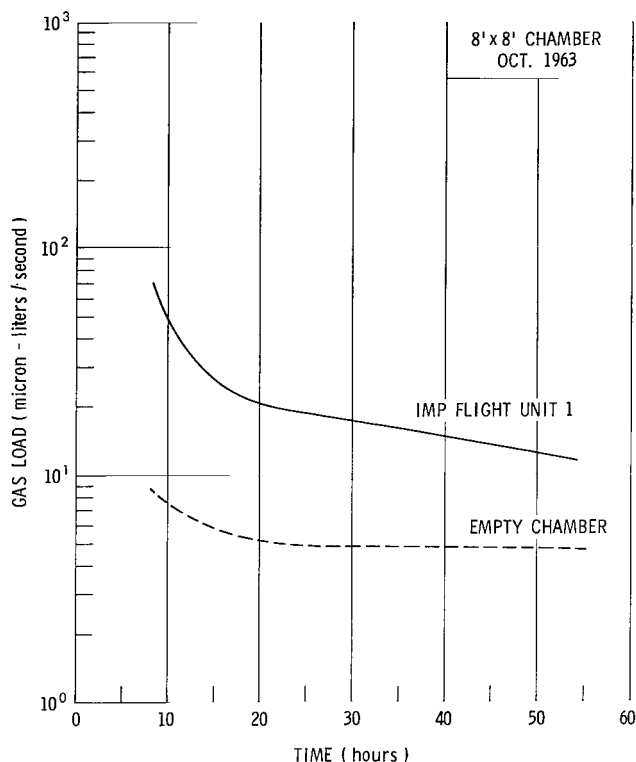


Figure 5—Gas-load vs time curves for IMP cold test at  $-10^{\circ}\text{C}$ .

after ten and twenty hours of pumping time, respectively. At reduced temperature, the spacecraft gas load varied from approximately one to twenty and 0.2 to 10 times the background gas load of the chamber after ten and twenty hours of pumping time, respectively. The reduction of spacecraft gas load with continued pumping does not appear to be a linear function with time. Limited data on spacecraft subjected to continuous pumping times in excess of 100 hours indicates that the gas load varies from one to three times the background gas load of the chamber.

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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